McBlare: A Robotic Bagpipe Player[1]

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ABSTRACT

McBlare is a robotic bagpipe player developed by the Robotics Institute at Carnegie Mellon University. McBlare plays a standard set of bagpipes, using a custom air compressor to supply air and electromechanical "fingers" to control the chanter. McBlare is MIDI controlled, allowing for simple interfacing to a keyboard, computer, or hardware sequencer. The control mechanism exceeds the measured speed of expert human performers. On the other hand, human performers surpass McBlare in their ability to compensate for limitations and imperfections in reeds, and we discuss future enhancements to address these problems. McBlare has been used to perform traditional bagpipe music as well as experimental computer generated music.

Keywords: bagpipes, robot, music, instrument, MIDI

1. INTRODUCTION

In 2004, Carnegie Mellon University's Robotics Institute celebrated its twenty-fifth anniversary. In preparing for the event, it was suggested that the festivities should include a robotic bagpiper as an entertaining acknowledgement of Carnegie Mellon's technical reputation and Scottish connection.[2] We set out to build a robotic system that could play an ordinary, off-the-shelf traditional set of Highland Bagpipes with computer control. The system is named McBlare.

Mechanized instruments and musical robots have been around for centuries. [6] Although early mechanical instruments were usually keyboard-oriented, many other electro-mechanical instruments have been constructed, including guitars and percussion instruments. [7, 8, 10] Robot players have also been constructed for wind instruments including the flute [9] and trumpet [1, 11].

We are aware of two other robotic bagpipe projects. Ohta, Akita, and Ohtani [5] developed a bagpipe player and presented it at the 1993 International Computer Music Conference. In this player, conventional pipes are fitted to a specially constructed chamber rather than using the traditional bag. Their paper describes the belt-driven "finger" mechanism and suggests some basic parameters as a starting point for the design:

- 4 mm finger travel;
- 20 ms total time to open and close tone hole;
- 100 gf minimum closing force for tone holes.

Sergi Jorda also describes bagpipes used in his work, consisting of single pitched pipes that can only be turned on and off. [2] In a separate email communication, Jorda indicated that "Pressure is very tricky" and may depend on humidity, temperature and other factors. In contrast to previous efforts, we decided to use off-the-shelf bagpipes to retain the traditional bagpipe look and playing characteristics.

Additional basic information was obtained by meeting with Alasdair Gillies, CMU Director of Piping, and Patrick Regan, a professional piper. We observed and videotaped their playing and tried to learn what we could about the instrument and playing techniques. From slow-motion video (25% speed) we estimated the fastest fingering to be about 15 Hz. Required finger pressure on the chanter appeared to be very light. We noted breathing cycle periods of about 4 seconds, and measured the time to exhaust the air from the bag playing a low A: 12 seconds; and a high A: 8 seconds. This gives a rough indication of the air flow requirement to be between 0.045 and 0.07 cubic meters per minute (1.6 and 2.5 cubic feet per minute), based on a measured bag volume of 0.0093 cubic meters (0.33 cubic feet). Alasdair said he maintains a pressure of 32" water column (7.9 kPa or 1.15 PSI) in the bag. Soshi Iba, experienced piper and then PhD candidate in Robotics,

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[2] Andrew Carnegie, who founded Carnegie Mellon (originally the Carnegie Institute of Technology), was born in Scotland. The University has an official tartan, the School of Music offers a degree in bagpipe performance, and one of the student ensembles is the pipe band.

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also provided substantial input and was our primary test subject.

We give an overview of McBlare, beginning with a brief description of bagpipes and how they work. There are two major robotic components of McBlare: the air supply, and the chanter control, which are described in Sections 3 and 4. One of the major difficulties we encountered has been properly setting up the bagpipes and coaxing them into playing the full melodic range reliably. Section 5 reports on our findings and current status.

2. Bagpipes

Bagpipes are some of the most ancient instruments, and they exist in almost all cultures. There are many variations, but the most famous type is the Highland Bagpipes (see Figure 1), and this is the type played by McBlare. There are three long, fixed pipes called drones. Two tenor drones are tuned to the same pitch, which is traditionally called A, but which is closer to $B\flat_4$. The third drone (bass drone) sounds an octave lower. Drones each use a single reed, traditionally, a tongue cut into a tube of cane, more recently, a cane or artificial tongue attached to a hollow body of plastic or composite material. The fourth pipe is the chanter, or melody pipe. The chanter is louder than the drones and uses a double reed, similar in size to a bassoon reed, but shorter in length and substantially stiffer. Like a basson reed, however, it is constructed around a small copper tube, or “staple”.

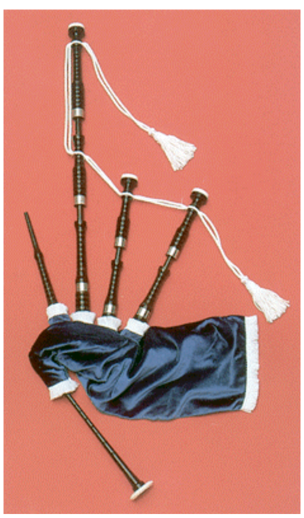

Figure 1. Traditional Highland Bagpipes.

The chanter has sound holes that are opened and closed with the fingers, giving it a range from G_4 to A_5 (as written). All four pipes are inserted into the bag, a leather or synthetic air chamber that is inflated by the player’s lung power through a fifth pipe, or blowstick. This tube has a one-way check-valve, so the player can take a breath while continuing to supply air to the pipes by squeezing the bag under his or her arm to regulate pressure.

Reeds at rest are slightly open, allowing air to pass through them. As pressure increases and air flow through the open reed increases in response, the Bernoulli effect decreases the pressure inside the reed, eventually causing the reed to close. The resulting loss of airflow reduces the pressure drop inside the reed, and the reed reopens. When things are working properly, the pressure fluctuations that drive the reed are reinforced by pressure waves reflected from the open end of the pipe, thus the oscillation frequency is controlled by the pipe length. The acoustic length of the chanter is mainly determined by the first open sound hole (i.e., the open sound hole nearest to the reed), allowing the player to control the pitch.

Pressure regulation is critical. It usually takes a bit more pressure to start the chanter oscillating (and more flow, since initially, the reeds are continuously open). This initial pressure tends to be around 8.3 kPa (1.2 pounds per square inch). Once started, the chanter operates from around 5.5 to 8.3 kPa (0.8 to 1.2 psi). The drone reeds take considerably less pressure to sound than does the chanter reed, and drones operate over a wider pressure range, so it is the chanter reed that determines the pressure required for the overall instrument. Unfortunately, the chanter tends to require lower pressure at lower pitches and higher pressure at higher pitches. At the low pitches, too high a pressure can cause the pitch to jump to the next octave or produce a warbling multiphonic effect (sometimes referred to as “gurgling”). If insufficient pressure is maintained on the chanter reed for the higher pitches, it will cease vibrating. Thus, there is a very narrow range in which the full range of the chanter is playable at a fixed pressure. Furthermore, pressure changes affect the chanter tuning (much more than the drones), so the chanter intonation can be fine-tuned with pressure changes. Typically, this is not done; rather, experienced pipers carefully attempt to adjust the stiffness and position of the reed in the chanter so as to be able to play the full 9-note range of the chanter with little or no pressure variation.

In some informal experiments, we monitored air pressure using an analog pressure gauge while an experienced player performed. We observed that air pressure fluctuated over a range from about 6.2 to 7.6 kPa (0.9 to 1.1 psi), with a tendency to use higher pressure in the upper register. Because of grace notes and some fast passages, it is impossible to change pressure with every note, and we speculate that the player anticipates the range of notes and grace notes to be played in the near future and adjusts pressure to optimize their sound and intonation.

Whether pressure should be constant or not is not well understood. For example, Andrew Lenz’s “bagpipejourney” web site described how to construct and use a water manometer. He says “Theoretically you should be playing all the notes at the same pressure, but it's not uncommon for people to blow harder on High-A.” [3]

3. The Air Supply

McBlare uses a custom-built air compressor. A 1/16 HP, 115VAC electric motor drives a gearbox that reduces the speed to about 250 rpm. Two 76 mm (3”) diameter air pump cylinders, salvaged from compressors for inflatable rafts, are driven in opposition so that they deliver about 500 pump strokes per minute. (See Figure 2.) The radius of the crank arm driving the cylinders is adjustable from 15 mm to 51 mm (0.6” to 2.0”); we found that the smallest radius provides adequate air flow, calculated to be 0.034 cubic meters per minute (1.2 cubic feet per minute).[1] A small air storage tank sits between the pump and the bagpipes. The bagpipes are connected with a rubber hose that slips over the same tube that a human performer would blow into. By blowing in air more-or-less continuously, we can achieve a fairly steady pressure without squeezing the bag. (Earlier designs called for a mechanical “squeezer” but at 7 kPa (1 psi), a squeezer in contact with many square inches would have to be very powerful, adding significantly to McBlare’s weight and complexity.)

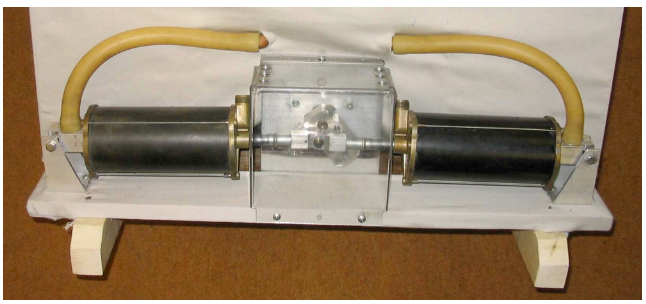

Figure 2. The McBlare air compressor. Electric motor (not visible) drives eccentric (center) through a gearbox. Eccentric drives two air pump cylinders (right and left) in opposition.

Pressure regulation is very simple at present. First, the stroke length of the pump cylinders is adjustable to set the flow rate just above what is needed by the bagpipes. Second, a relief valve, which is simply a weighted plug, vents high pressure (around 10 kPa or 1.5 psi) to prevent over-pressure and avoid damaging the bagpipes. A second bleed valve can be adjusted to release air and lower the pressure.

4. The Chanter Control

The chanter requires “fingers” to open and close sound holes. Analysis of video indicates that bagpipers can play sequences of notes at rates up to around 25 notes per second. Human players can also uncover sound holes slowly, partially, using either an up-down motion or a sideways motion. The design for McBlare restricts “fingers” to up-and-down motion normal to the chanter surface. Fortunately, this is appropriate for traditional playing. The actuators operate faster than human muscles, allowing McBlare to exceed the speed of human pipers.

McBlare’s “fingers” are modified electro-mechanical relays. (See Figure 3.) Small coils pull down a metal plate, which is spring loaded to return. Lightweight plastic tubes extend the metal plate about 3 cm, ending in small rubber circles designed to seal the sound hole. The length of travel at the sound hole is about 2.5 mm, and the actuators can switch to open or closed position in about 20 ms. The magnet coils consume about 1 Watt each, enough to keep the mechanism warm, but not enough to require any special cooling. The magnet mechanism has the beneficial characteristic that the finger force is maximum (around 100 gf) with the magnet closed, the point at which finger force is needed for sealing the tone hole.

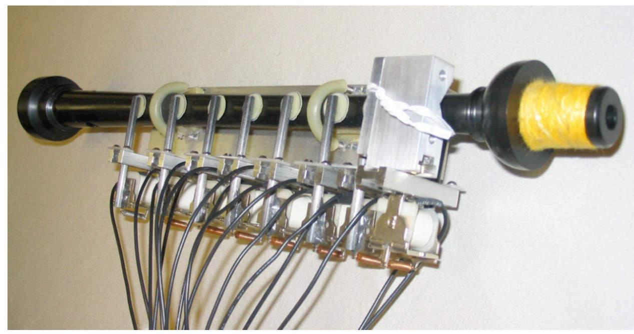

Figure 3. Chanter is mounted on aluminum block along with electromagnetic coils that open and close sound holes using rubber pads at the end of lightweight plastic tubes.

The whole “hand” assembly is designed to fit a standard chanter, but the individual finger units can be adjusted laterally (along the length of the chanter) and vertically. The lateral adjustment accommodates variations in hole spacing. The vertical adjustment is critical so that the magnet closure point corresponds to the point of finger closure.

The actuator current is controlled by a current driver IC, which is in turn controlled by a microcontroller. The microcontroller receives MIDI, decodes MIDI note-on messages to obtain pitch, and then uses a table-lookup to determine the correct fingering for that pitch. MIDI notes outside of the bagpipe range are transposed up or down in octaves to fall inside the bagpipe range.

5. Findings and Status

The chanter control works extremely well. The speed allows for authentic-sounding grace notes and some very exciting computer-generated sequences. In its original configuration (see Figure 4), McBlare included a small Yamaha hardware MIDI sequencer so that it could play traditional tunes that we found on the web in the form of standard MIDI files. We also developed a small laptop-based program to allow users to select and play a tune or to record and play a melody from a MIDI keyboard. A further option can automatically ornament the recorded melody

[1] This is less than the 0.045-0.07 cubic meters per minute based on bag deflation measurements above. This may be due to differences in instruments and/or measurement errors.

using typical bagpipe figures that are automatically extracted from our database of MIDI files.

Figure 4. Garth Zeglin with McBlare shortly before its debut at the Robotics Institute's Twenty-Fifth Annivesary. Bagpipes are mounted on a display board that conceals the pump and additional electronics.

The use of MIDI control makes it possible to adapt all sorts of controllers to McBlare, including keyboards (which are very useful for experimentation), novel sensors, or even MIDI bagpipe controllers. [4] For now, the bagpipes themselves are so captivating that we have not pursued the use of special controllers. Since bagpipes have no control over dynamics, pitch is really the only controllable parameter. Therefore, any bagpipe interface should be particularly agile as a pitch controller.

As might be expected, there is considerable mechanical noise generated by the air compressor. In addition, the electro-mechanical chanter "fingers" make clicking sounds. However, the chanter is quite loud, and few people notice the noise once the chanter begins sounding.

Under ideal conditions, McBlare can play sequences covering the full range of pitches from G_4 to A_5. More typically, however, the lowest two notes do not cooperate at the pressures needed to sustain oscillation at the top end of the range. We suspect a number of factors are causing difficulties. First, chanter reeds are very delicate and problematic even for human players. They are made from natural cane and take time to adjust and break in. McBlare's reeds seem to be drying out in the dry compressed air. Second, the pump does not deliver absolutely steady air pressure, and sometimes a very slight modulation can be heard that matches the pump frequency. Third, we have no dynamic control over pressure, whereas the lowest notes can often be brought under control if the pressure is lowered.

6. Future Work

We intend to explore options for chanter reeds, including artificial reeds, adding a humidifier to the pump input to prevent reeds from drying out during performances, and regulating the air pressure to avoid fluctuations caused by piston strokes. Recent experiments with human lung power providing steady pressure indicate that pressure regulation is needed. As a last resort, we might control air pressure via MIDI to coax less-than-ideal reeds into sounding over their full range. One possibility is to adapt a standard gas pressure regulator with a servo motor to change the pressure setting. Further experiments and measurements of expert pipers should tell us whether this is really necessary. An automated "arm" to squeeze the bag is still a possibility, and could provide some interesting control aspects to the problem.

Since the chanter pitch can be adjusted with air pressure, with minimal effect on the drone pitch, there is the possibility of tuning the bagpipes by capturing the chanter and drone audio on separate channels, analyzing their fundamental frequencies, and then adjusting pressure to bring the chanter reed in tune. Again, this practice is frowned upon by experts, so we need to conduct further observations and experiments to determine whether pressure changes are really necessary.

Once the basics are under complete control, there are some finer points of piping to consider. One is the fact that humans can cover tone holes partially to achieve pitch bending effects. We chose to ignore this possibility, which would greatly complicate the design and which is not required for most performances. However, a design that allows for pitch bends, either using tone holes—or perhaps a radical change such as a telescoping chanter or slide-whistle-like piston—could offer many new interesting musical possibilities.

7. ACKNOWLEDGEMENTS

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